

¹The New Ultra Low Noise Diplexed X-Band Microwave Feed for NASA 70-m Antennas

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Abstract- This paper describes the configuration, detail design, and performance of a new ultra low noise diplexed X-band microwave feed system, called X/X diplexing feed, for the Deep Space Network (DSN) 70-m antennas. In this microwave feed, the uplink signal is combined with the downlink signal in a diplexing junction placed near the input of a wide-band feedhorn. This configuration allows the majority of the components in the downlink path to be placed in a cryogenically cooled container, resulting in a drastic reduction in the loss (noise temperature) of the feed. Combined with low noise High Electron Mobility Transistor (HEMT) amplifiers, this feed provides the lowest noise diplexed feed in the DSN. The total noise temperature of the 70-m antennas with this feed is estimated to be 16.1 Kelvin.

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1. INTRODUCTION

DSN owns and operates three 70-m antennas, which are geographically located to provide near continuous communication for NASA's deep space probes. These antennas are located at Goldstone, California, Madrid, Spain, and Canberra, Australia. Each 70-m antenna contains 3 feedcones. Currently one feedcone contains microwave feed equipment for X-band downlink only (called XRO). The second feedcone contains microwave feed equipment for S-band downlink and uplink (called SPD). See Figure 1 for the XRO and the SPD feedcones optics and configuration. The third feedcone is dedicated to radar and radio astronomy applications.

X-band uplink has been available on DSN 34-m antennas since mid 1980s. However, in 1995, due to the advent of smaller spacecraft requiring higher data rates and the need for high power X-band for emergency situations, NASA funded the Jet Propulsion Laboratory (JPL) to implement X-band uplink on all 70-m antennas. The 70-m antennas offer an additional gain of approximately 6 dB compared to the 34-m antennas.

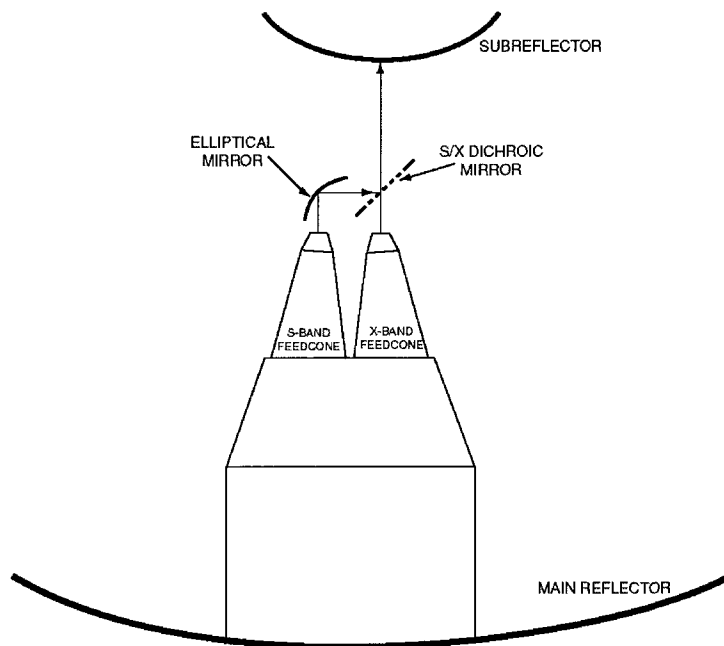


Figure 1. NASA 70-m Antennas S/X-Band Optics

The most critical requirement in the design and development of microwave feeds for the DSN is low noise downlink capability, and in the case of diplexed feeds, high power transmission, simultaneously. Currently the existing DSN antennas operate with a total antenna X-band noise temperature of about 20 to 32 Kelvin depending on if Maser or HEMT amplifiers are used, respectively. For diplexed systems, the transmitter power is nominally about 20 kW. What makes the design and development of these

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microwave feeds challenging is isolating the super sensitive Low Noise Amplifiers (LNA) and receivers from the high power signal, its harmonics, and the spurious signals generated by the high power transmitter located in the same feedcone.

In the traditional microwave feeds, a waveguide diplexer and a stop band filter were used to provide the necessary isolation between the uplink and downlink signals (See Figure 2). Even though these components were designed in oversized waveguides, they still introduced significant additional loss for the downlink paths. For this reason, JPL started an R&D effort to design an ultra low noise feed (X/X diplexing feed) by cryogenically cooling all or most of the components in the downlink signal path to liquid Nitrogen temperatures. The major problem in doing so was the waveguide diplexer. With 20 kW passing through the diplexer it was not practical to cool it to liquid Nitrogen temperatures. To alleviate this problem, the diplexer was eliminated and in its place a diplexing junction was developed which combined the X-band uplink and downlink signals near the input of the feedhorn (see figure 3). With this design it was then possible to place most of the downlink path components, including some of the filters, required for high isolation, in a cryogenically cooled container. The reduction in the receiver losses were so high that less expensive and more reliable HEMT amplifiers could be used in place of the lower noise Maser amplifiers and still achieve better performance than the traditional designs.

As part of the X-band upgrade, a wide-band S/X-band dichroic mirror was also designed and developed. This mirror reflects the S-band signal while passes the X-band uplink and downlink signals through with very low loss (see figure 1).

In this paper, the design of the traditional DSN diplexed microwave feeds is compared with the new X/X diplexing microwave feed. Also, the design of the S/X-band dichroic mirror and the performance predictions of the 70-m antennas at X-band will be discussed.

2. TRADITIONAL DSN DIPLEXED MICROWAVE FEED

A simplified block diagram of the traditional DSN diplexed feed is shown in Figure 2. This design employs two Maser amplifiers for redundancy. Other major components include a wide-band corrugated feedhorn, a wide-band polarizer with rotary joints, an orthomode junction, an X-band Preamplifier Filter (XPF) and a diplexer. The polarizer converts the Right- or Left-Hand Circularly Polarized (RCP or LCP) signals into vertical and horizontal signals. The orthomode junction then guides these signals to its two rectangular waveguide ports, respectively. By rotating the polarizer by 90 degrees, the RCP and the LCP signals can be routed to either ports of the orthomode junction. This allows for a low-noise path and a diplexed path for the signal. The low-noise path contains the XPF, which provides 70 dB of rejection at the uplink frequencies for protection of the LNA. The diplexed path contains a low noise diplexer that separates the uplink and downlink signals. Two waveguide switches provide redundancy by allowing the use of either LNAs with the low-noise or the

diplexed paths. In this feed, all components are at room temperature except the LNAs. The noise contribution of the microwave circuit in this feed is approximately 8.3 and 17.3 for the low-noise and the diplexed paths, respectively. The overall antenna noise temperature is 19.7 Kelvin for low noise and 28.7 Kelvin for diplexed operation.

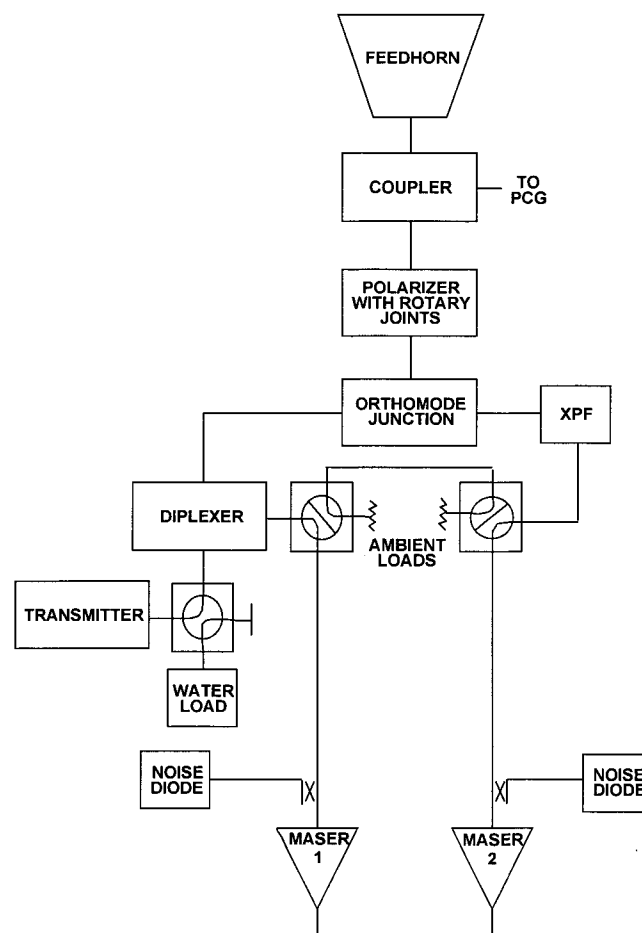


Figure 2. Simplified Block Diagram of the Traditional DSN Diplexed Feed

3. NEW DSN X/X DIPLEXING MICROWAVE FEED

Figure 3 shows a simplified block diagram of the new DSN X/X diplexing microwave feed. In this design, a diplexing junction is used for combining the uplink and downlink signals. This diplexing junction is a 6-port device. Two of the ports are in circular waveguide. One is connected to a 22 dB feedhorn through a coupler and the other is connected to the LNA package through a transmitter reject filter and an ambient load sliding switch. The filter provides 40 dB of rejection for the fundamental transmitter frequency. The ambient load switch is used for calibration of the LNAs. The other 4 ports, which are in rectangular waveguides, are used for injection of the uplink signal. These ports are combined into one port with a network of Hybrids, Tees, and a polarization selection switch. For additional protection against the spurious signal generated by the transmitter, an 80 dB absorptive filter is used between the polarization switch and the transmitter.

In the downlink path, the signal coming out of the ambient load switch is guided to the LNA package. The LNA package consists of a cryogenically cooled container that holds the rest of the downlink path components. These components include a polarizer/orthomode junction to convert the circularly polarized signal to linear polarization, additional band pass filters for protection of the super sensitive HEMT LNAs, and circulators for improving the match and reducing the standing wave generated between the reflective filters in the downlink path. In this design, one LNA is used for the RCP signal, the other for the LCP signal. No provision is made available to switch the RCP or the LCP signal from one LNA to the other. This means that no redundancy is provided for the LNAs. Using highly reliable HEMT amplifiers and maintaining spare LNA packages at each antenna site mitigates the risk of losing data due to the failure of one of the LNAs.

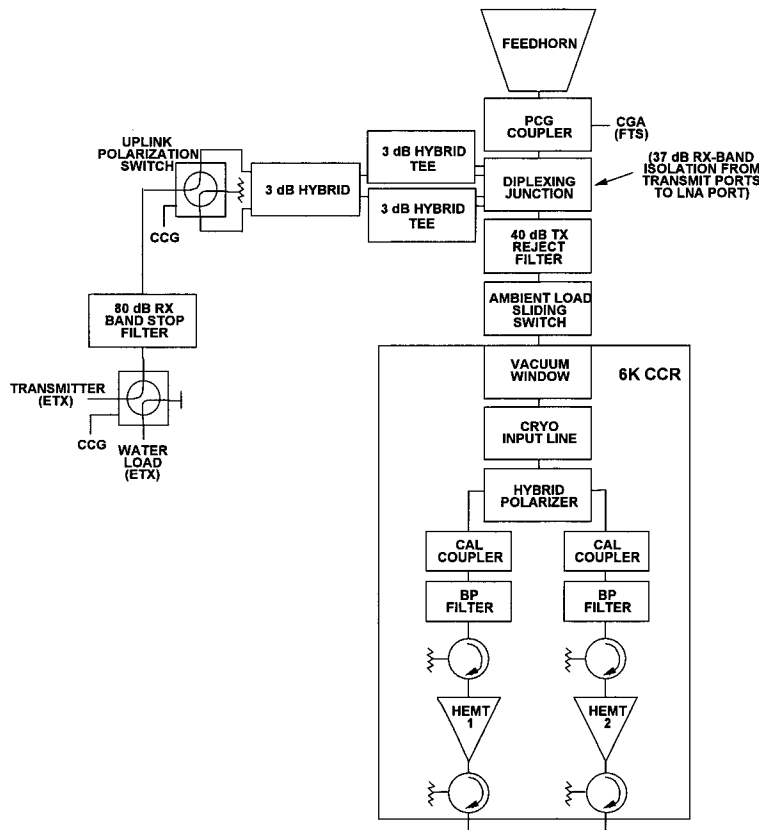


Figure 3. Simplified Block Diagram of the X/X Diplexing Feed

The noise contribution of the microwave circuit in this feed is approximately 2.7 Kelvin for diplexed operations. The overall antenna noise temperature is approximately 18.6 Kelvin with 9.5 Kelvin LNAs. It is estimated that with lower noise HEMT LNAs, under development at this time, the total antenna noise will be reduced to 16.1 Kelvin. Table 1 shows the breakdown of the predicted, measured, and expected final noise temperature of the individual components of this feed at 8450 MHz.

Table 1. Noise Temperature Breakdown of X/X Diplexing Feed components in Kelvin

Item	Predicted Noise Temperature	Measured Noise Temperature	Expected Final Noise Temperature
Feedhorn	1.0	0.8	0.8
PCG Coupler	0.3	0.3	0.3
Diplexing Junction and Filter	1.7	1.4	1.4
Ambient Load Switch	0.2	0.2	0.2
LNA	6.0	8.4	7.0
Total	9.20	11.1	9.7

4. S/X-BAND DICHROIC MIRROR

Currently, the NASA 70-m antennas support X-band downlink only. Therefore, the S/X-band dichroic mirror used in Figure 1 is a narrow band design capable of reflecting the S-band uplink and downlink band (2025 MHz to 2300 MHz) and passing the X-band downlink band (8400 MHz to 8560 MHz). With the new diplexed microwave feed, the antennas need a wide-band dichroic mirror that passes the X-band uplink frequencies (7145 MHz to 7190 MHz), as well as the downlink frequencies, with very little loss.

As part of upgrading the 70-m antennas (to add X-band uplink), a new dichroic mirror was designed to accommodate the X-band uplink and downlink frequencies. This design uses Cross-shaped holes to provide low loss and minimize grating lobes due to the wide frequency range it must operate at [1]. Figure 4 shows the perforated section of this dichroic mirror. This mirror is fabricated in hard oxygen free copper using a wire Electric Discharge Machine.

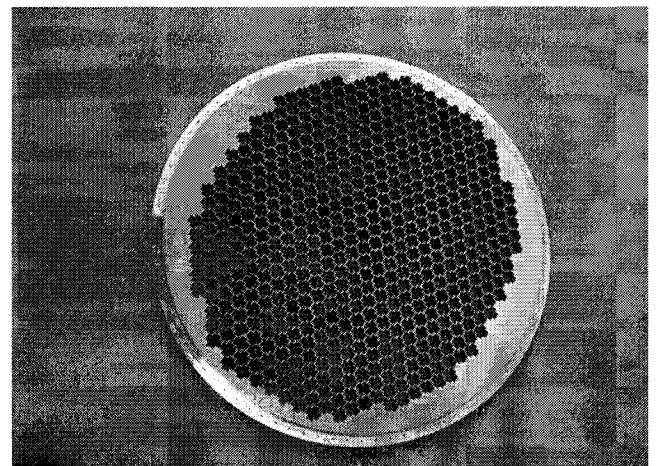


Figure 4. The Wide-Band S/X Dichroic Mirror

The cross-shaped holes used here can be packed tighter than circular holes and therefore, it is possible to design a wide-band dichroic mirror that can support the X-band uplink and downlink bands without undesired grating lobes. Figure 5 shows the theoretical and measured power reflection coefficient of this mirror for a circularly polarized signal incident at a 30-degree angle with respect to the normal to the plane of the mirror [1]. As can be seen, the mirror is designed to have two resonant frequencies: one at the center of the uplink band, the other at the center of the downlink band. There is an excellent agreement between the theoretical and measured values. The error between the theoretical and measured resonant frequencies is less than 1%. The measured noise contribution of this mirror is approximately 1.2 Kelvin.

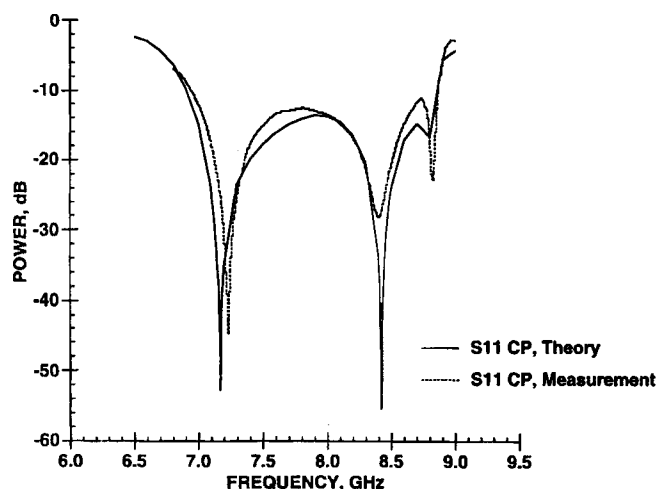


Figure 5. Power Reflection Coefficient: Comparison of Measurement and Theory for Circular Polarization

5. CONCLUSION

This paper presented the design of the new DSN X/X Diplexing microwave feed for the NASA 70-m antennas. This design provides a configuration, which allows most of components in the downlink path to be cryogenically cooled. Table 2 shows a comparison between the performance of the old DSN diplexed feed and the new X/X diplexing feed. As can be seen, the new feed improves the diplexed performance of the antennas by about 2.5 dB. Additionally, by utilizing HEMT LNAs, the new feed will be much easier to maintain and has lower implementation cost and much lower lifetime cost.

6. ACKNOWLEDGMENT

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7. REFERENCES

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Table 2. NASA 70-m Antennas Noise Temperature Performance with Old Diplexed Feed VS. X/X Diplexing Feed, Kelvin

Item	Old Diplexed Feed, Low Noise Path	Old Diplexed Feed, diplexed path	X/X Diplexing Feed Predicts	X/X Diplexing Feed, Current	X/X Diplexing Feed, Goal
Cosmic Background	2.5	2.5	2.5	2.5	2.5
Antenna	3.8	3.8	3.8	3.8	3.8
Microwave Circuit	8.3	17.3	3.2	2.7	2.7
Low Noise Amplifier	5	5	6	8.4	7.0
Follow-on	.1	.1	.1	.1	.1
Total	19.7 K	28.7 K	15.6 K	17.5 K	16.1 K

Farzin Manshadi is a Technical Group Supervisor at the Jet Propulsion Laboratory, California Institute of Technology. In this position, he has led the design, development, and implementation of microwave subsystem as well as antenna measurements and calibrations for NASA Deep Space Network antennas. In the last few years, he has also been the task manager of the 70-m X-Band Uplink Task responsible for upgrading the NASA 70-m antennas to support X-band uplink. He has an MS and a PhD in electrical Engineering from the University of California at Los Angeles.

